6.1 Introduction

The following are important areas to be considered in any future plans of the XFD:

- Adequate support is required for improvement of the operating instruments in order to provide the highest reliability for user operations at the APS facilities. Some of these needs are met with the limited funds made available by the DOE under the Accelerator Improvement Program (AIM).

- R&D is necessary at this time to fully utilize the potential of the APS. This includes operating the APS in a "top-off" mode in which stored beam current is kept at a nearly constant value. In addition, the APS will be operated in the future at 300 mA of stored particle beam. Handling the heat load of the radiation from such a beam with possible 5-m-long undulators requires R&D on some components of the beamline. This work needs to begin immediately in order to fully exploit the high brilliance of which the APS is capable.

- Planning for the implementation of beamlines in the remaining 14 sectors of the storage ring is necessary. This is consistent with DOE's highest priority to fully and effectively utilize currently operating facilities. The first 20 sectors of the APS are being utilized to support the general scientific goals of the already established CATs. New collaborative teams are likely to be formed in the coming years. XFD is constantly looking for opportunities to attract new communities interested in using the APS.

- The research and development objectives of the present CATs are broad, and thus beamline instruments were designed to cater to the general community. While this approach has been essential for the support of the U.S. synchrotron community at large, it has precluded exploration of dedicated scientific areas for which long-term development of specialized instruments is required. Such dedicated beamlines built around focused user groups will be proposed to utilize some of the remaining 14 sectors. These proposals will be developed such that the special purpose beamlines will be jointly built by XFD and the user groups at a rate of 1-2 beamlines per year starting in 1999.

- There is world-wide interest in a so-called fourth-generation synchrotron radiation facility, which will be an x-ray free-electron laser (FEL) based on a linac using the “self-amplification of stimulated emission” (SASE) concept. The APS linac, with its 450-600 MeV capability, is suitable for testing the SASE concept in the 500-1000 Å range. Superior expertise and experience in the field of undulator development, so essential for any x-ray FEL effort, is singularly available in XFD. This would be another initiative requiring major R&D effort.

Strategic planning has been performed by XFD to develop new initiatives to meet the future APS goals indicated above. Considerable R&D is required in order to prepare these initiatives, as is continued dialogue with the

user community. Support for all such R&D activities is currently not provided through the normal DOE funding process. Hence support is derived for many activities from the LDRD funds distributed by the ANL Director through a laboratory-wide competitive process.

XFD also constantly seeks other sources of funds to support R&D, performed in collaboration with the APS users, that can either lead to new capabilities for the users or support possible new initiatives. These efforts were addressed in Chapter 5.

6.2 Accelerator Improvement Program Plans

The following AIM activities have been planned for 1997 and 1998 in order to improve the quality of XFD operations in support of APS users:

1. Extract storage-ring, ID, and beamline front-end operational parameters and provide the data to APS users in a usable format in real time.

2. Install higher accuracy and more reliable linear encoders on all 18 undulators to provide real-time gap information to user beamlines.

3. Interface critical PSS and EPS parameters with the APS control system.

4. Fabricate and install smaller-aperture front-end masks.

5. Develop interface and software to provide continuous monitoring of the ID front-end vacuum.

6. Install residual gas analyzers for ID vacuum chambers.

7. Expand the PSS-EPICS interface for both BM and ID beamlines.

8. Upgrade ID stepping-motor power supplies and controllers.

9. Install UHV diagnostics instrumentation and component test enclosures.

10. Add a PSS electronic validation system.

11. Replace vacuum hardware in ID chambers.

12. Install DSP units for the XBPMs in the ID front ends.

13. Replace front-end critical components.

14. Add oven and magnetization systems to treat ID magnets.

6.3 Enhancement of APS Performance

The following three areas reflect future enhancements of APS performance, which will require upgrades of certain components maintained by XFD:

- Providing 5.0-m-long undulators to specific CATs

- Implementing “top-off” mode to keep stored beam current nearly constant

- Operating the storage ring with stored current of 300 mA

The R&D in support of these activities has been planned for 1998-99. Operation of the storage ring with the above enhancements requires additional capital funds to install upgraded components. For example, all the undulators currently provided to users are 2.5 m long, and longer devices will require additional funds for construction and installation. The photon stops currently used in the ID beamline FEs are designed to handle radiation power generated with 100 mA of stored beam current. Upgrading all the ID FEs to handle the radiation power generated by 300 mA stored beam will require increased capital funds. Commensurably, higher power will also have to be handled by the beamline mechanical and optical components, and these upgrades will require additional R&D and funding support.

A comprehensive plan that includes these enhancements will be developed by XFD in the 1998-99 period in consultation with various CATs. Support for this plan will be sought from DOE's Presidential Science Facilities Initiative.

6.4 New Collaborative Access Teams

In order to support a new CAT, the APS has to obtain funds for instrumentation behind the shield wall, i.e., the ID and the beamline FEs, for each of the new sectors. At this time, three new CATs are preparing proposals for additional sectors: one for protein crystallography, the second for ultrahigh pressure measurements, and the third to support small industry. In addition, SRI-CAT is seeking a fourth sector at the APS for the development of polarization techniques that have not been well addressed by other CATs.

The commercial (COM)-CAT, which will perform work on behalf of small industry, is seeking funds for capital construction of its beamlines; its operations will be supported by the collection of service charges from its industrial customers. The COM-CAT proposal has now been submitted for funding to the state of Illinois. This proposal includes the funds required for XFD to build the ID and the FEs for COM-CAT. Future CAT proposals will include a similar arrangement so that the funds for equipment behind the shield wall will not have to be sought separately.

6.5 Strategic Plans for Dedicated Beamlines

As pointed out above, 14 sectors of the APS are still available for experimental programs. The development of these sectors is consistent with DOE's mandate to fully and effectively utilize currently operating facilities before considering additional projects. This initiative hence addresses more opportunities for exploring new scientific research fields using dedicated beamlines.

Currently, 20 of the 34 APS sectors are assigned to various CATs. Each sector utilizes a generic set of techniques for using the x-ray beam for the investigation of various science and technology problems. This approach has precluded specialized beamlines dedicated to one (often complex) technique, which can address some of the frontier areas of research. For these cases, the user community would prefer dedicated instruments.

The dedicated beamlines will be chosen from the list presented below. For each beamline, we present a strategic analysis to aid the selection. The final selection of beamlines will be based on the level of interest of the respective user groups. For each beamline, funds will be jointly requested (from various sources including federal agencies and industry) by the APS and the beamline user group. Some of the beamlines require new R&D effort, and the R&D for some are currently supported through LDRD funds.

Funds for the construction and operation of these beamlines will be sought from DOE's Presidential Science Facilities Initiative, with the intent of completing 1-2 beamlines per year.

BEAMLINE 1: Very High X-ray Energy Scattering (ID)

The basic purpose of this beamline would be to perform the following studies in the 50-150 keV energy range:

- Compton scattering studies of electron momentum distribution
- High-Q diffraction from molecular solids, glasses, and liquids to study structural details down to 0.1 Å
- Small angle scattering from bulk solids to study precipitate phases, voids or defects, etc.
- Structural studies of composite materials and fluids in confined geometries
- Studies of solid/liquid interfaces, corrosion, etc.

Currently no beamlines of this type have been planned at the APS, ESRF, or SPring-8. This is a new research opportunity, and a demonstration will be performed during FY1997-98 on the 1-ID-A (SRI-CAT) beamline.

For this program to succeed, development of a superconducting undulator is required. XFD has the world's best expertise in this area, and the preliminary design for a prototype device to be built jointly with Novosibirsk is complete. The prototype will be tested on an SRI-CAT beamline.

BEAMLINE 2: Static and Dynamic Small Angle X-ray Scattering (ID)

The basic purpose of this beamline would be to serve as a national facility to study length scales from 10 Å to 10 μ, with the capability for anomalous small angle x-ray scattering (SAXS) experiments down to millisecond time resolution using area detectors. The beamline will be of interest to the condensed matter physics, materials sciences, and biology communities.

Currently a BM beamline at the ESRF is used for biological studies and has capabilities similar to those at the NSLS. At the APS, two of the CATs (CMC and DND) have planned limited capabilities, with about 10-20% of their beam time available for SAXS experiments. SPring-8 has yet to plan a facility. The need and unique ability to probe length scales using SAXS at a third-generation facility was emphasized by the Eisenberger-Knotek report of 1983. The leadership in the U.S. can bring together an active group of researchers in

different disciplines to use this dedicated beamline.

BEAMLINE 3: Sub-Nanosecond Temporal Resolution Studies (ID)

The basic purpose of this beamline would be to use high brilliance, timing detectors, and the bunch structure of the storage ring for studies of conformational changes, chemical reactions, phase transitions, and defect propagation. The potential applications are:

- Chemical reactions on catalyst surfaces and supports
- Polymer morphology under applied stress
- Metallurgical phase changes under processing conditions
- Conformational changes in proteins
- Pump-probe studies

The beamline will be of interest to the condensed matter physics, chemical and materials sciences, bioscience, and industrial communities.

Currently at the APS, limited work is planned with instruments designed for select problems. The applications include dynamics of biomolecules (Bio-CARS), photosynthesis (BESSRC), fiber crystallization (DND), and nuclear coherent diffraction (SRI). The program was highlighted in the Eisenberger-Knotek report but has not received the attention it deserves.

Key R&D required for the program to succeed includes the development of timing detectors, mechanical and optical techniques to sort photons from bunches, and synchronization techniques between the storage-ring bunch pattern, pump signal and probe technique, and the development of stroboscopic methods. The subject is a key candidate for future LDRD support.

BEAMLINE 4: Coherence and Interference Techniques (ID)

The basic purpose of this beamline would be to utilize the coherence of radiation in the x-ray range from undulator sources. Fundamental understanding of the coherence and its use will be the focus for this beamline. Some of the studies include:

- Dynamics of complex fluids
- Surface diffusion
- Relaxation modes in glasses and liquids
- Fundamental physics of x-ray coherence and interference

Major users of this beamline will be from the condensed matter physics and materials sciences communities.

The importance of coherence was realized only recently. Three CATs at the APS (IMM, MHATT, and SRI) plan to perform basic studies to establish this important field of research. The new opportunities in this area are yet to be fully explored.

For this effort to succeed, an immediate need is an understanding of x-ray coherence and how it can be propagated through the various optical components of a beamline without being destroyed. This work is being undertaken by some of the APS CATs, particularly IMM and SRI. This field is now in the exploratory phase. It is already clear that coherence studies cannot be seriously pursued on multipurpose beamlines. By 1998, we expect that the requirements for a dedicated beamline will be well defined.

It is expected that the planned work at the APS and the LDRD-supported research will lead to many new applications of x-ray coherence and, in turn, a new dedicated user community. This beamline is even more important when we realize that x-ray coherence is a prime basis for fourth-generation sources.

BEAMLINE 5: Three-Dimensional Imaging (ID)

This beamline would be devoted to three-dimensional holographic and tomographic studies with hard x-rays. An x-ray holographic technique in the hard x-ray range has yet to be developed and will open new areas of application. Applications for tomography down to 100 Å spatial resolution will be found in biology, materials sciences, and engineering. The research focus will be in the areas of catalysis, corrosion science, and electronic components, with some problems demanding real-time studies.

The biology, condensed matter physics, and materials sciences and industrial communities will be the principal users of this beamline.

The initial work on holographic imaging has been carried out by SRI-CAT at long wavelengths. This work was supported by LDRD funds. In the hard x-ray range, the technique has yet to be established, and R&D will be performed by SRI-CAT. No such effort is planned anywhere else. There have been many attempts (NSLS, Geo-CARS and CMC-CAT) to perform tomography of special materials; however, there are no dedicated efforts planned at the APS. More importantly, the proposed spatial resolution of the real-time measurements is unique to this beamline. Imaging received very high recognition in the Eisenberger-Knotek report, and the proposed beamline would fulfill this expectation.

Key R&D required for the program to succeed is the development of timing 2-D detectors and holography techniques. In addition, rapid image data reduction techniques need to be developed for effective implementation of tomographic imaging. The support to begin this software development was recently awarded through a Grand Challenge Grant from DOE to XFD, GeoCARS-CAT, and Argonne's Mathematics and Computer Science Division.

BEAMLINE 6: Advanced Materials Engineering Research (ID)

The proposed beamline will provide three unique capabilities for the processing of advanced materials:

- high-power x-ray beams from undulators
- capability to focus the high power to micron-size areas using appropriate optics

- sufficient x-ray penetration to deposit this high power density deep inside the materials being processed

In addition, x-ray assisted processes, such as chemical vapor deposition (CVD) and etching, will be investigated.

The principal users will be from university engineering departments, DOD, the national labs, and industry.

This is a new program that will have a major impact on engineering fields. Basic expertise exists in the Beamline Engineering Group in XFD. However the initial work will be pursued in collaboration with university engineering departments.

The research will be started in FY 1998 with LDRD support. It is expected that even the preliminary results will attract a large number of materials engineers who can form the core group. In addition, many outreach activities to educate engineering departments about the capabilities of the APS will be pursued during 1998. Key R&D required to establish the program will be performed on an SRI-CAT beamline.

BEAMLINE 7: Micro-Component Fabrication (BM)

This beamline will exploit the special properties of a APS BM source, including high energy, high flux, and a high degree of collimation, to perform deep x-ray lithography (DXRL) for micromachining. The fabrication applications of micromechanical parts include micromotors, gear chains, x-ray optics, and pressure sensors. The beamline is expected to support internal and external client needs.

There is already significant interest in this beamline from industry, NASA, the national labs, and APS users.

The R&D work on DXRL has been carried out by SRI-CAT with the support of LDRD funds. The DXRL technique is being evaluated for resolution, depth of exposure, aspect ratio, and throughput. Industrial partners are collaborating with XFD in developing the processes. Most European activity in this area is being carried out at the Forschungszentrum in Karlsruhe. No such work is planned by any of the APS CATs.

Key techniques required for the program to succeed are currently being developed by XFD. The industrial outreach activity will be increased as soon as a few prototype devices are made with the SRI-CAT beamline.

A marketing plan will be developed early in 1998, and a marketing workshop of potential clients from universities, industry, and the national labs will be organized soon after to form the core community.

BEAMLINE 8: Archaeometallurgy Research (BM)

This beamline will be developed for the needs of a new community of x-ray users, the archaeometallurgists. The interest of this group is now nucleating at the APS with a collaboration between the Oriental Institute of The University of Chicago and XFD. The focus of the beamline is to provide analysis and composition of archaeometallurgical samples to provide insight into the metal-lurgical processes used in ancient times, primarily during the Bronze Age. The capabilities of the APS BM sources are well

suited for these users. The beamline is expected to support international user groups.

Contacts include the Society of ArchaeoTec, the Ancient Metallurgy Research Group, and the Historical Metallurgy Society.

Our understanding of ancient (e.g., early Bronze Age) technological advances is both amazing and intriguing. However, very limited physical methods have been used to date to evaluate the industrial processes used, such as metal extraction and smelting. The x-rays from the APS provide a unique opportunity for this potential group of users. No such effort has been planned at any other synchrotron radiation facility. The unique complimentarity of the expertise at the Oriental Institute and the XFD would be exploited by this beamline proposal.

Key techniques required for the program to succeed are currently being developed by XFD (SRI-CAT) jointly with the Oriental Institute. The core community of archaeo-metallurgists has been identified.

BEAMLINE 9: X-ray Imaging for Medical Diagnostics Research (ID)

This beamline would be devoted to the development of new tools for non-invasive imaging medical diagnostics. Some of the examples of imaging include coronary angiography, mammography, and specific antigenic foci (breast cancer, melanoma, or lymphoma). The purpose of the facility is only to develop the techniques for imaging various subjects, including human organs.

The initial work in this field was started at Stanford University, and currently the main focus is at the NSLS, where much of the work on both angiography and mammography is being carried out. A beamline dedicated to medical imaging is under construction at the ESRF and will begin operation in summer 1997. Many past attempts to begin this activity at the APS have not matured, primarily owing to a lack of leadership from the medical community. Imaging received very high recognition in the Eisenberger-Knotek report, and the proposed beamline would fulfill this expectation.

Key R&D required for the program to succeed has taken place at the Stanford Synchrotron Radiation Laboratory (SSRL), HASYLAB, and the NSLS. Further developmental work in the area of 2-D detectors will impact the field in a major way. Networking with hospitals (e.g., U of C) at the highest level of ANL management is required to find the necessary leadership for this beamline.

Once the leadership for this beamline effort has been identified, a workshop for potential users from hospitals and the national labs will be organized.

A bonus for such a beamline would be the ability to perform 3-D computer tomography of other large objects of special interest, such as ancient Egyptian mummies or turbine blades.

BEAMLINE 10: Radiation Therapy Research (BM)

This beamline would be devoted to studies on radiation therapy (and radiosurgery) procedures. The unique capability of microfocusing optics for x-rays (e.g., as developed by XFD) provides a unique opportunity to expose only the affected area for treatment. The technique

can be used concurrently to perform micro-tomography of the affected area to plan the treatment.

While radiation therapy is an established field of research at medical laboratories, the use of synchrotron radiation is totally new, and hence much effort will be required to attract interested medical researchers to a synchrotron and to evaluate the advantages of a strong radiation source.

Initial work at the APS must be carried out using future LDRD or similar program development funds in collaboration with researchers from The University of Chicago. Networking with hospitals (e.g., U of C) to find the necessary leadership for this beamline is the first step, followed by collaborative research. Key R&D efforts required for the program to succeed at a synchrotron radiation source can then be established.

BEAMLINE 11: Molecular Environmental Science (ID)

This beamline would be devoted to the special needs of the community performing research in the field of molecular environmental science. The community focuses on:

- Speciation, reactivity, and mobility of contaminants in aqueous solutions and their relationship to molecular biological processes
- The role of surfaces and interfaces in molecular environmental science
- The need for handling radioactive samples at synchrotron radiation facilities

Initial work in the area of environmental science has been done at the NSLS and SSRL; more work is planned at the Advanced Light Source (ALS) and APS. A 1995 workshop organized by DOE concluded that the planned beamlines at the APS (MR-CAT, GeoCARS-CAT, and PNC-CAT) "will not likely meet the increased demand after 1998 because of anticipated needs for service work on environmental samples." Future demand and the requirement for studying highly toxic and radioactive samples will dictate the need for a dedicated beamline at the APS with special environment, safety, and health protection features. There is a lab-wide interest in this area of research, and LDRD funds were provided to the ER Division in FY 1997.

Key R&D required for the program to succeed is in place. The implementation of the proposed beamline, however, requires major planning for safe handling of samples and their disposal. ANL has the best expertise and facilities (e.g., in the Bldg. 200 M-wing) for handling radioactive samples and, in particular, actinides.

BEAMLINE 12: X-ray Micro-fluorescence, Microimaging & Microdiffraction (ID)

The basic purpose of this beamline would be to perform both scanning and real-time studies of submicron-size areas using microprobe techniques. Applications of these tools in materials sciences, industrial fabrication, and biological systems are attracting very diverse users. Attention has also been focused on residual stress analysis and crack propagation in materials and recently on the capability of studying the dynamics of small particles using microfluorescence.

This beamline will attract scientists from the condensed matter physics, materials sciences, biology, soil science, environmental science, defense research, and industrial research communities.

Currently the techniques for submicron focusing are being developed by SRI-CAT. GeoCARS-CAT will set aside approximately 1/3 of the time on one of its beamlines for dedicated users from the soil science community. By 1999, UNI-CAT will build a beamline that will be dedicated roughly half-time to these studies. At the ESRF, a new beamline was added with the sole purpose of using microprobe techniques. The SRI-CAT strategic instrument station is already oversubscribed.

This is an easy area to market. The demand is now growing. The techniques are being refined by SRI-CAT. To support this program, XFD will continue to develop focusing optics (e.g., zone plates). The need for 2-D detector development will be crucial for real-time studies.

6.6 Strategic Plan for FEL Undulator Development

The basic purpose of this XFD effort is to design and build an extra long undulator, along with both particle and photon diagnostics, as a part of the APS FEL initiative. Production of 50-100 nm radiation is the prime objective of this project.

The availability of linac and accelerator expertise in ASD are prerequisites to this plan. XFD has the world's best expertise in the construction of magnetic devices, and this has been enhanced by collaboration with scientists from Novosibirsk. Concurrently, some demonstration experiments on this unique source will be performed.

Brookhaven National Laboratory has planned a similar capability based on a different principle of seeding the laser. SSRL has plans for a 0.1 nm FEL. The potential sponsor for the APS effort is DOE.

Key R&D required for the program to succeed is the development of a long undulator that includes the required diagnostics. XFD has performed all computations on the gain lengths to demonstrate this capability, and prototype undulators have been designed. These will be built in collaboration with Novosibirsk to reduce costs of fabrication. Funding for this activity has been made available from LDRD funds. The prototype device for testing the SASE concept will be ready early in 1998.

A parallel study on the transfer of coherence through beamline optics has been undertaken by SRI-CAT. More work is planned for 1998 to address the thermal problems related to the nanosecond power train from an FEL in the x-ray energy regime.

6.7 LDRD Program in Support of Long-Term Goals

The support needed to perform the R&D to prepare for the long-term goals described above is generally not provided through the DOE annual budget process. The main source of support for such R&D activities is derived from LDRD funds. Table 6.1 lists the LDRD programs funded for the 1996-98 period in support of the long-term goals of XFD.

Table 6.1 Current LDRD Programs in Support of the Long-Term Goals of XFD

Long Term Program	LDRD Program
1. FE Upgrade	1. CVD Diamond Imaging Detector (97-98)
2. Micromachining Beamline	2. Deep Etch Lithography (96-98)
3. Imaging/Coherence Beamline	3. Intensity Fluctuation Spectroscopy (96-98) Heterodyne Correlation Spectroscopy (96-98)
4. Ultrahigh Energy-Resolution Beamline	4. Fabry-Perot Cavity for Sub-meV Resolution (97-99) Anomalous Inelastic Scattering with meV Resolution (97-99)
5. X-ray FEL	5. Computational analysis to specify the requirements of an undulator to demonstrate the SASE concept, and prototype testing (97-99)